

The Urban Heat Island: Causes, Impacts, and Potential for Mitigation

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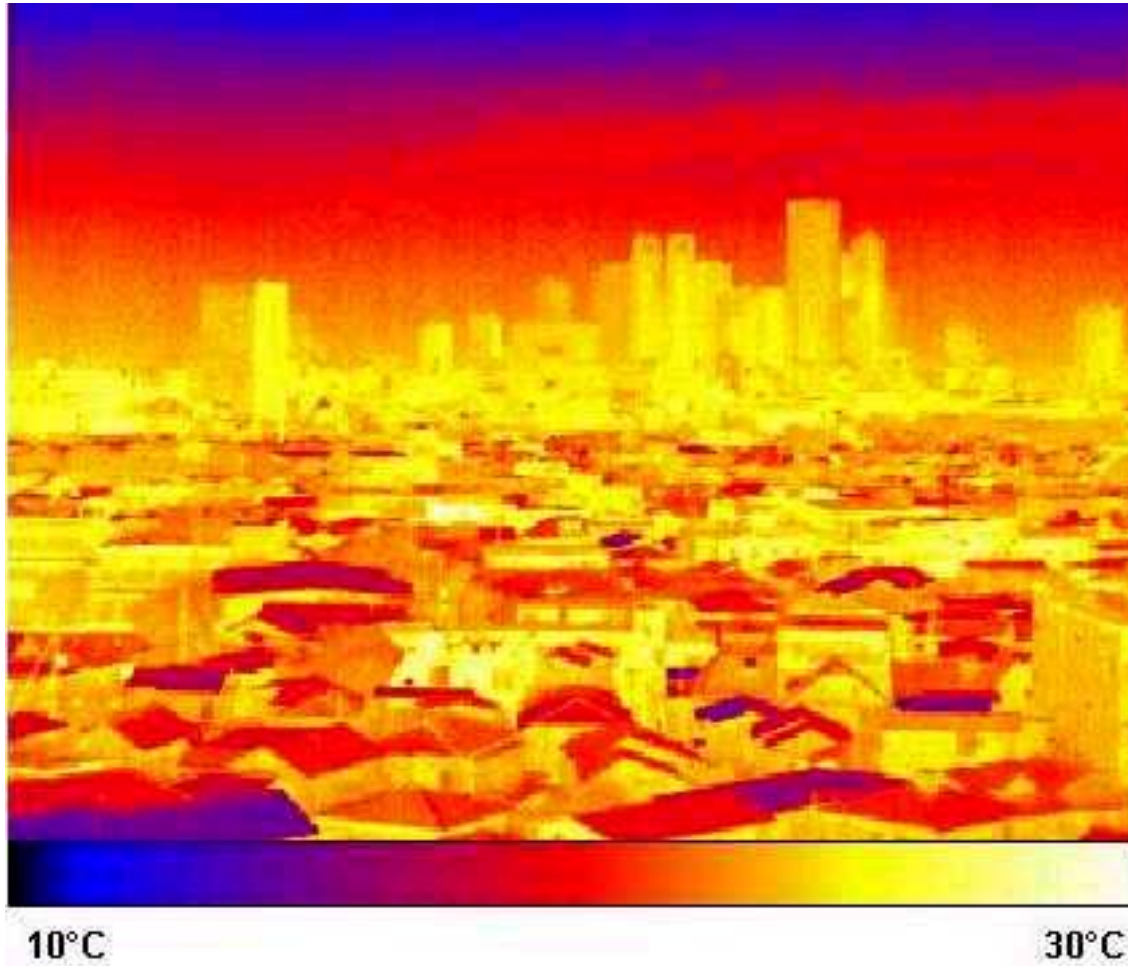
“The respiration of humans and animals, above all the fumes of innumerable chimneys, maintain above Paris a rust-colored haze which blocks the sun... it is impossible that (Paris) should not have a notably higher temperature than the surrounding country.”

– Emilien Renou, 1855.

“... the temperature difference between the countryside (and the city) is about 1° (C)”

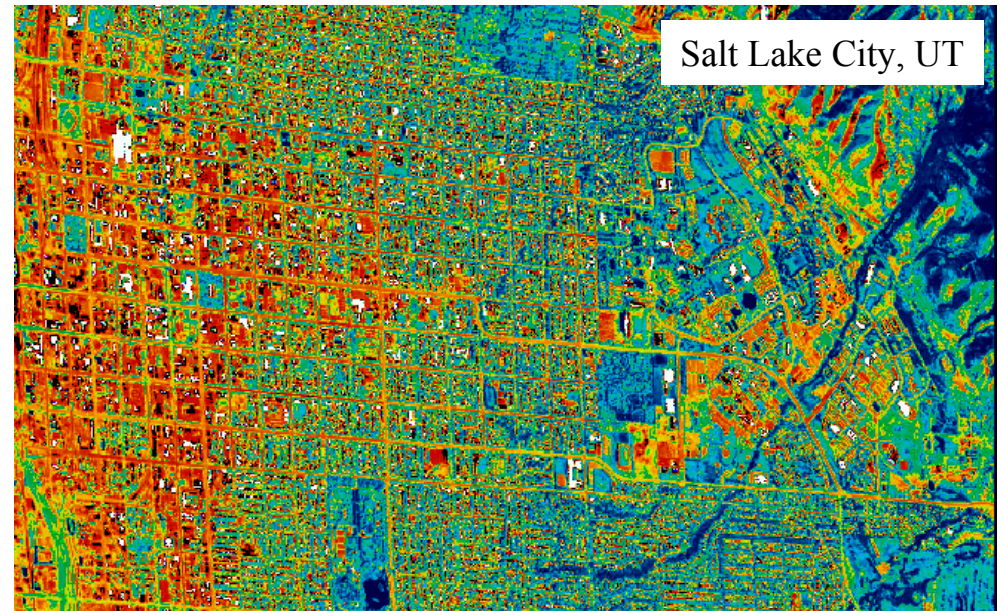
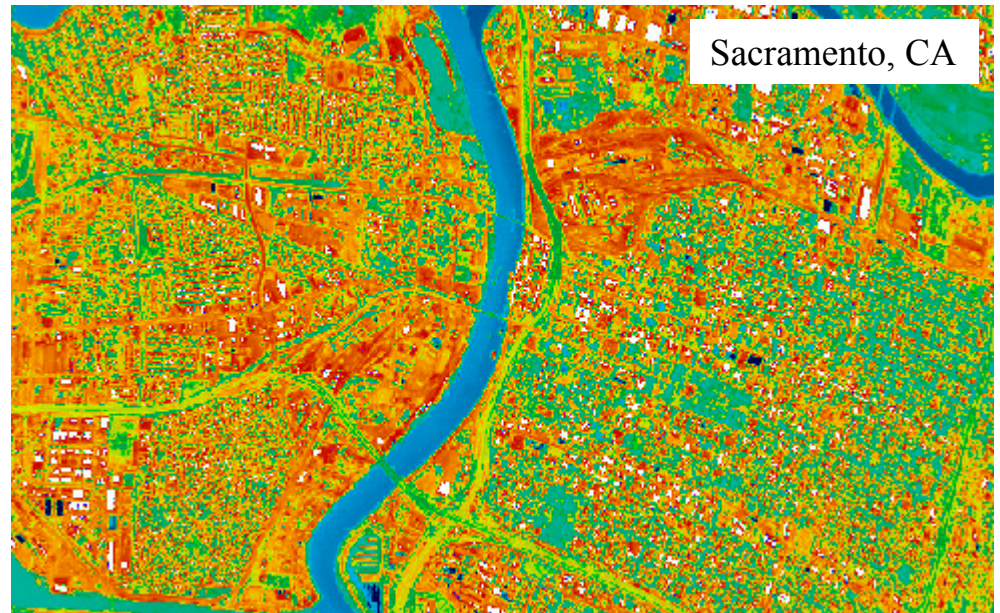
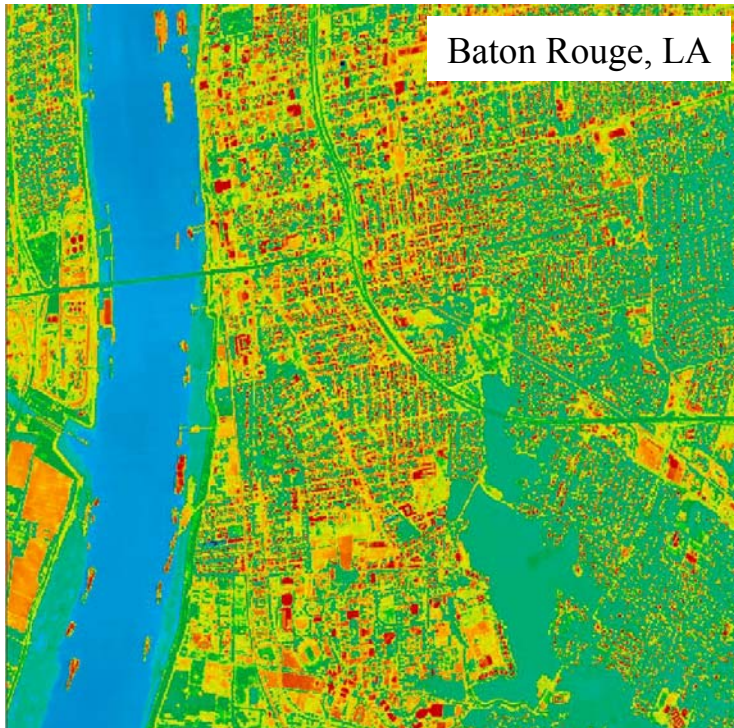
– Emilien Renou, 1868.

Tokyo, JAPAN



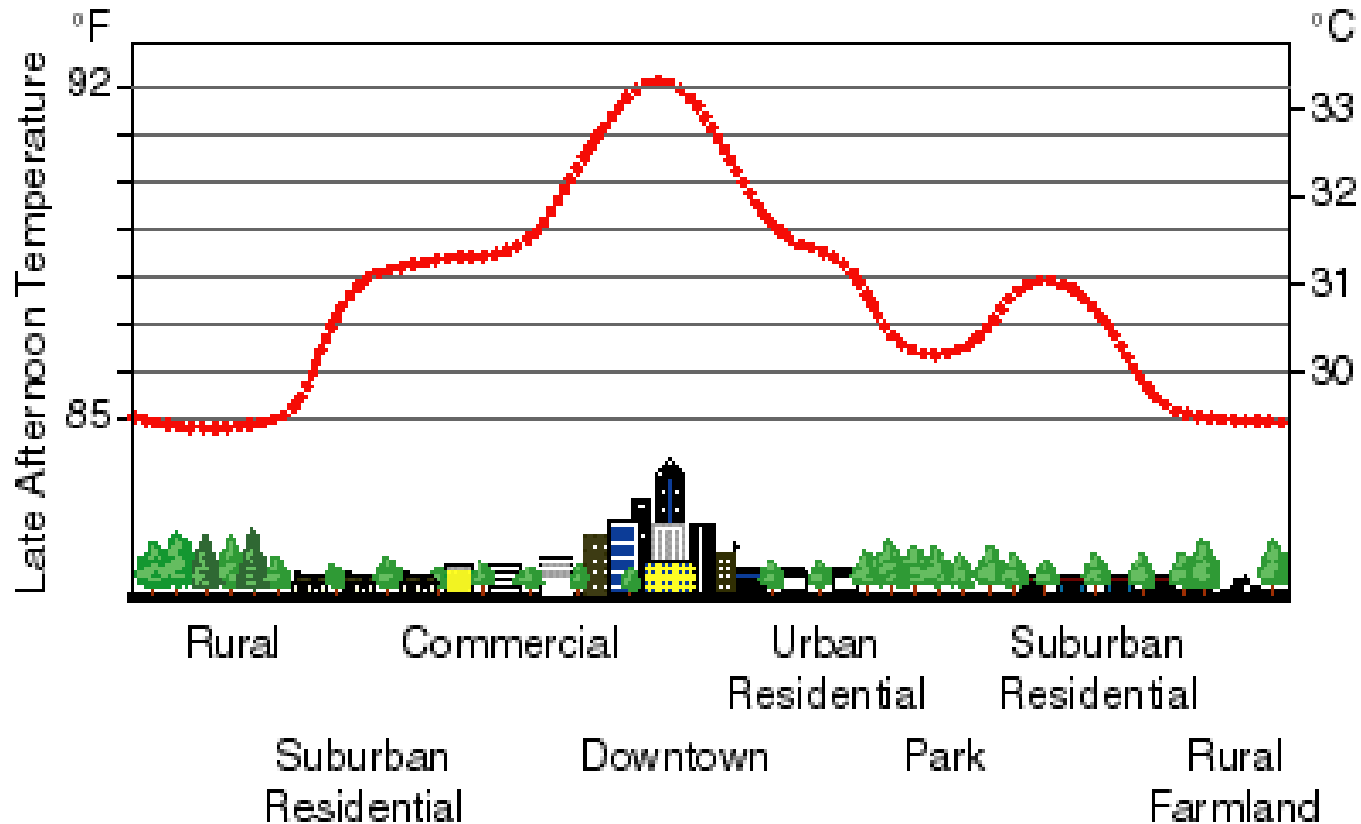
Images from: J. Voogt, U. Western Ontario and
M. Roth, National University of Singapore

Remotely-sensed urban heat islands



Images not to scale.

Sketch of an Urban Heat-Island Profile



Urban Heat Island – a working definition

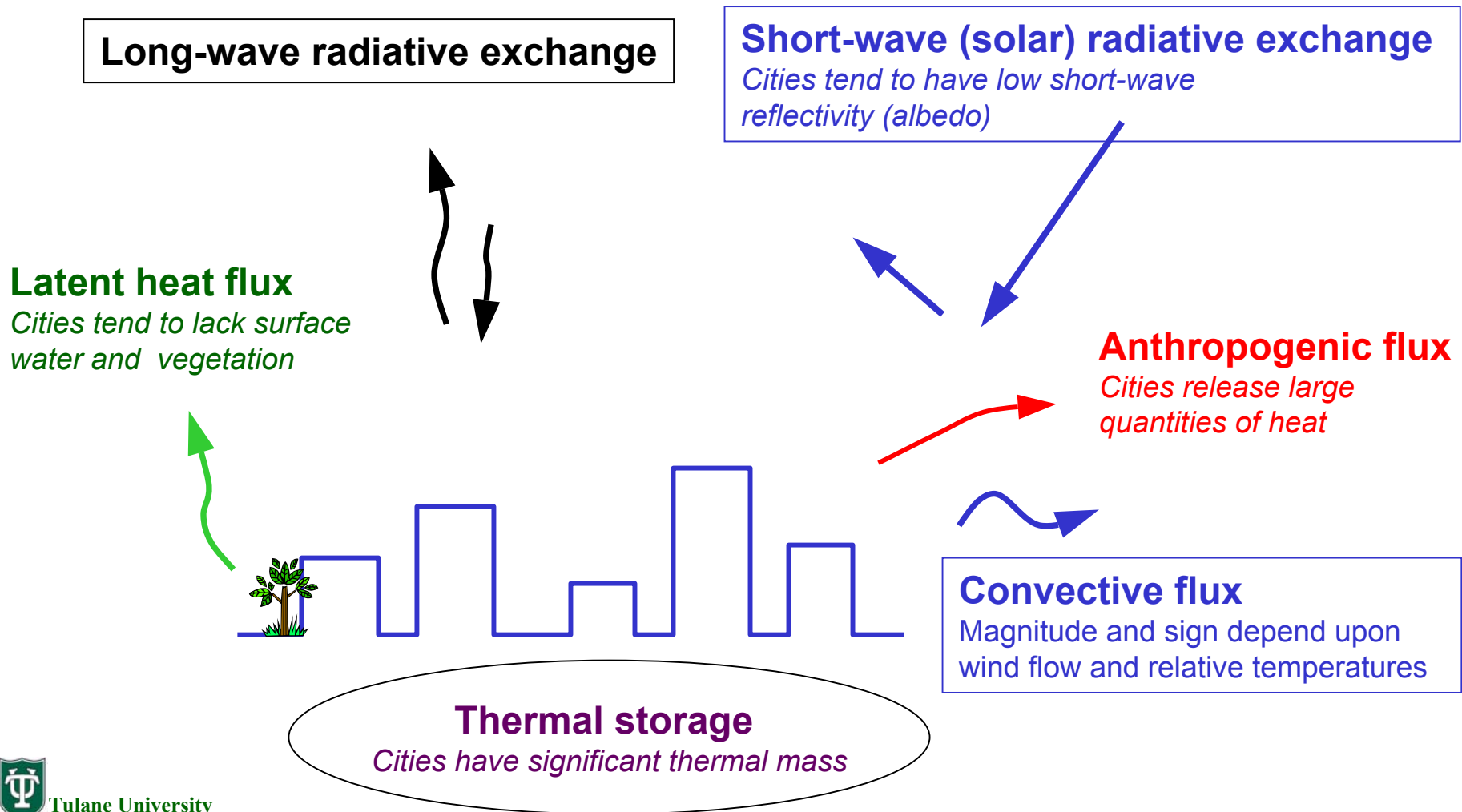
“An area of higher temperatures in an urban setting compared to the temperatures of the suburban and rural surroundings. It appears as an ‘island’ in the pattern of isotherms on a surface map.”

- Glossary of Weather and Climate, Ira Geer, Ed.

- Heat Island complexities include...
 - Diurnal, seasonal, and spatial variability
 - Air vs. surface temperature heat islands
 - Geographic/topographic causation
 - Importance of other weather variables

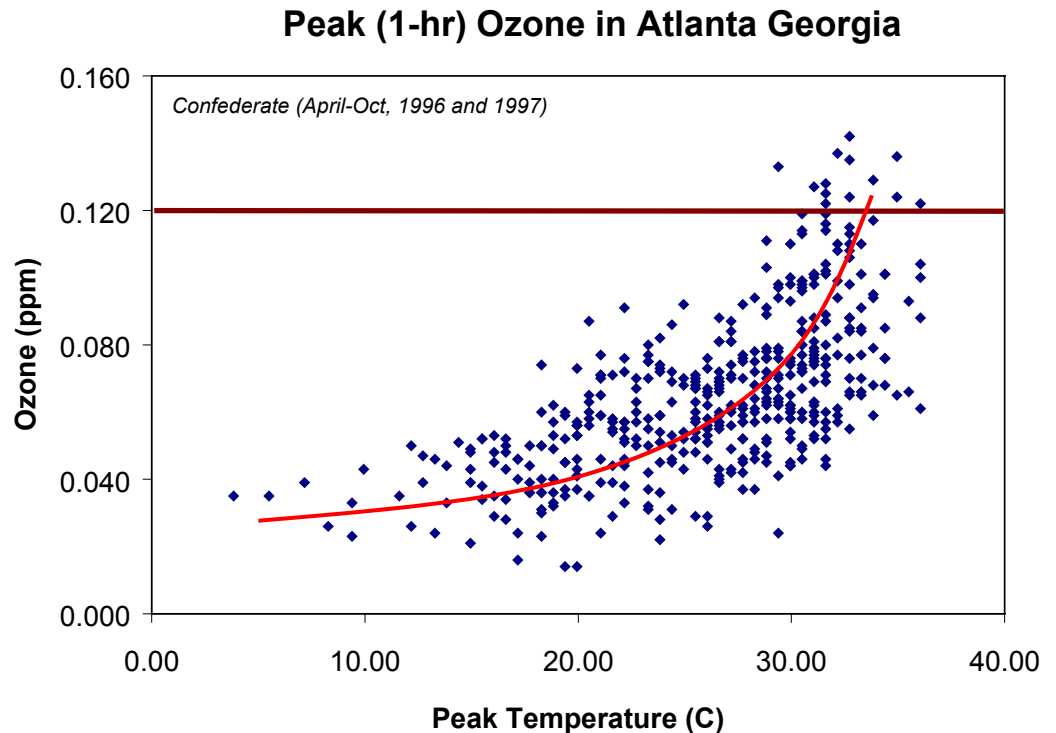
Causes and Consequences of Urban Heat Islands (UHI)

The Urban Energy Balance

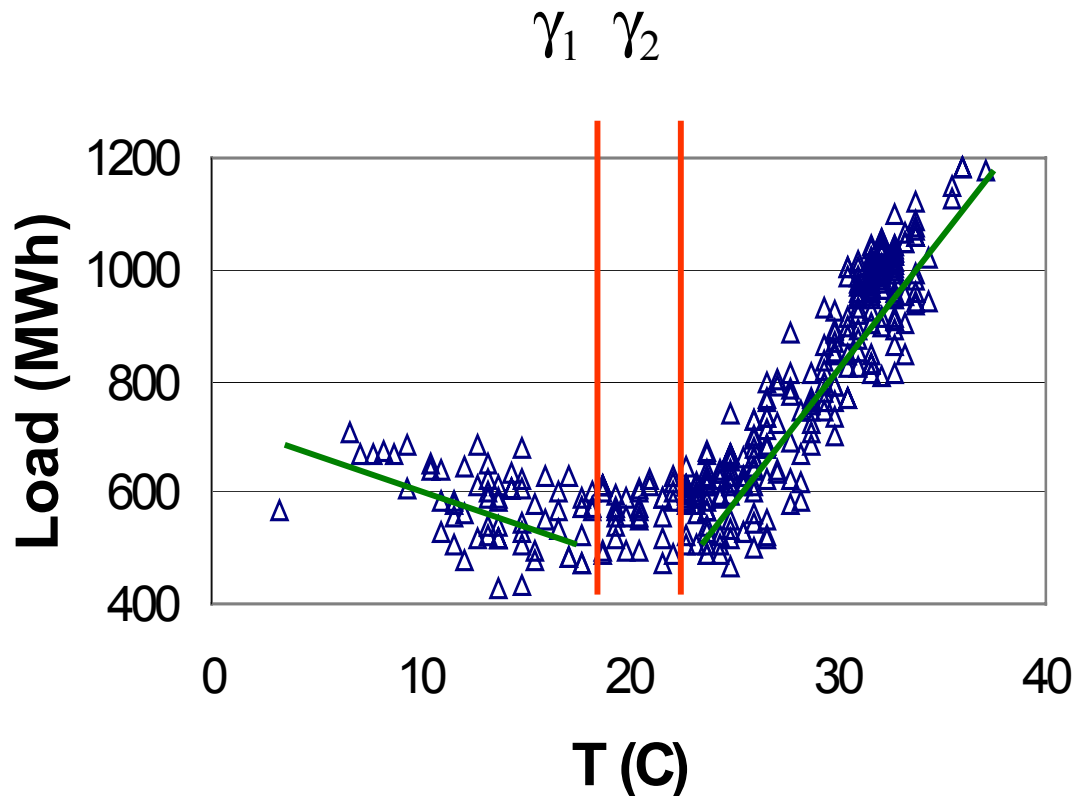


UHI Consequences – Air Quality

- Emissions
- Rate constants
- Mixing heights
- Wind patterns and convective transport



UHI Consequences – Energy (electricity)

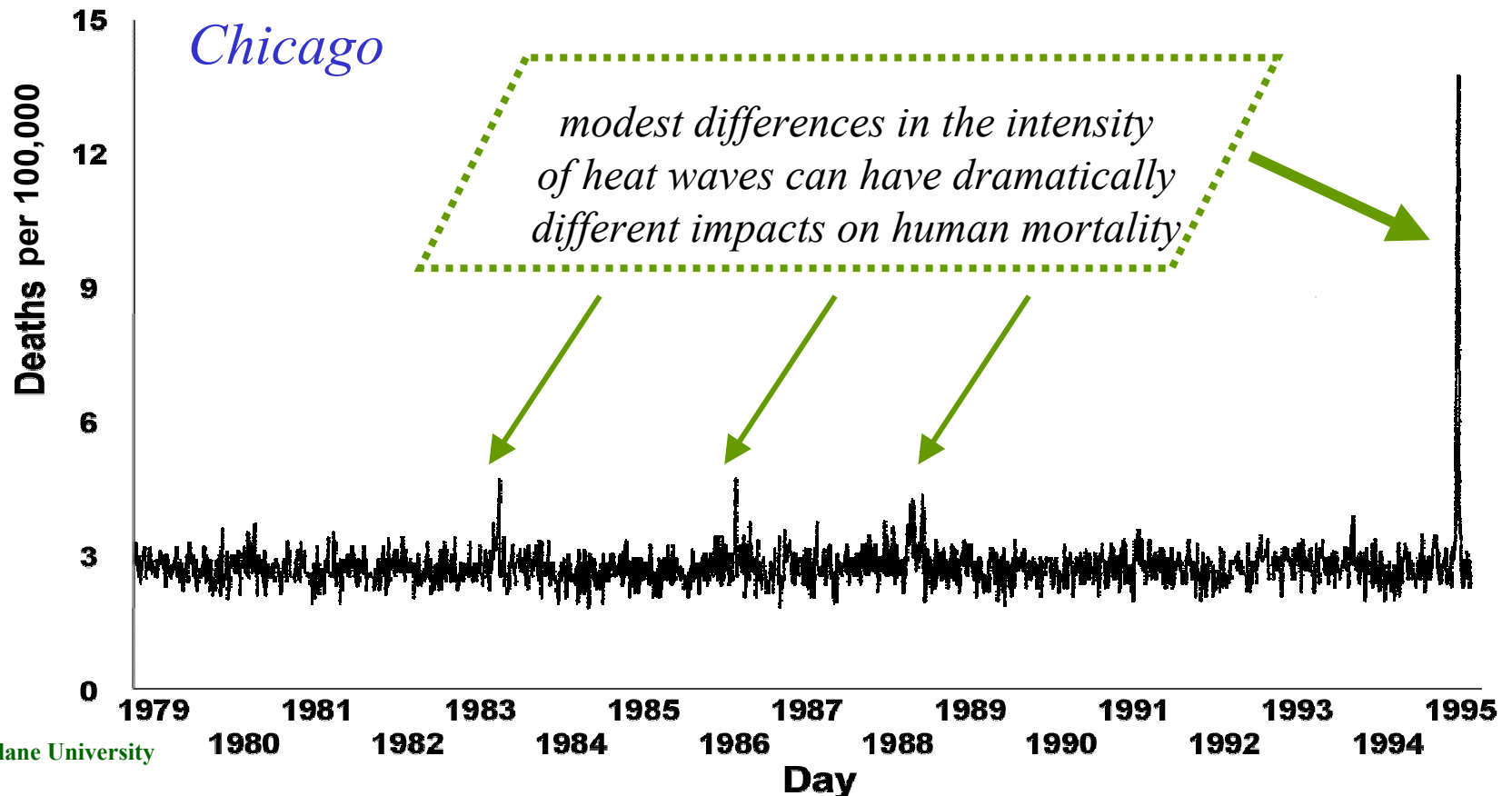


- Total & Peak loads
- Winter vs. summer
- Generation capacity requirements

UHI Consequences - Health

- Heat-related mortality

- During 1979-1996, exposure to extreme hot temperatures caused an **annual average of 381 deaths** in the United States (CDC)



Knowing the causes of the heat island suggests some possible solutions...

- 1. increase urban albedo**
- 2. increase urban vegetative cover**

Note: For a typical city 20 to 30% of land cover is roof, 30 to 40% is paved surfaces, and 20 to 30% is vegetative cover.

Increase Urban Albedo

$$\rho_{sw} = \frac{\int_{\lambda=0.2\mu m}^{2.5\mu m} \rho_{\lambda} G_{\lambda} d\lambda}{\int_{\lambda=0.2\mu m}^{2.5\mu m} G_{\lambda} d\lambda},$$



$$Albedo = \frac{\text{Reflected Solar Energy}}{\text{Incident Solar Energy}}$$

where, G_{λ} = spectral irradiation $\left(\frac{W}{m^2} \mu m \right)$

- Albedo for surfaces in the built environment

Black roof shingles	to	White shingles	to	Specialty coatings
0.05	--	0.30	--	0.70
Black asphalt	to	Concrete	to	Specialty asphalt coatings
0.05	--	0.25	--	0.50

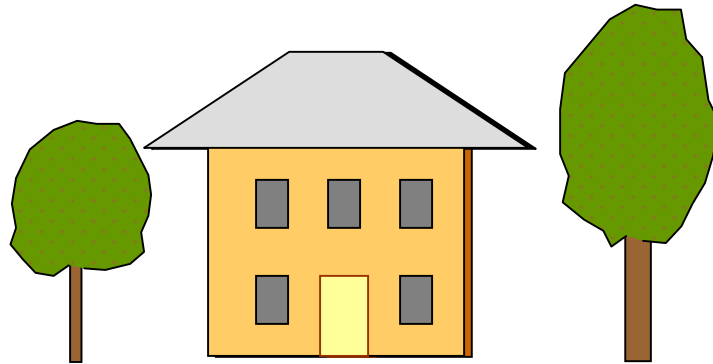
- Propose replacing rooftop and paved surfaces with higher albedo alternatives.
May be able to increase urban albedo by 0.10 to 0.20

Increase Urban Vegetative Cover

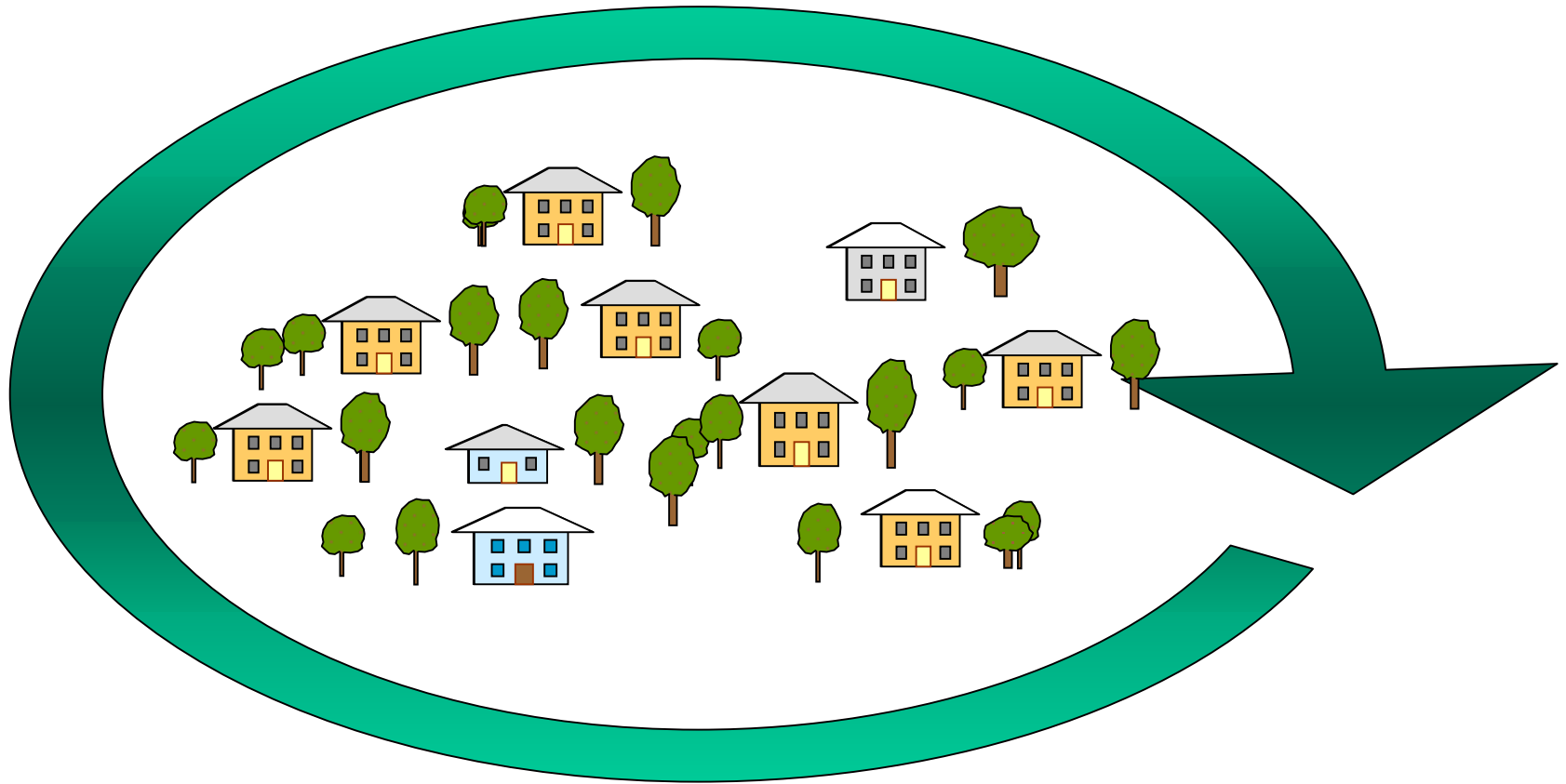
- Typical measure of urban vegetative cover is Fractional cover (F_v)
- $15\% < F_v < 30\%$ for most urban areas
- By planting trees to shade buildings and paved surfaces, and minimizing impervious surfaces we may increase the effective F_v by 0.10 to 0.20.



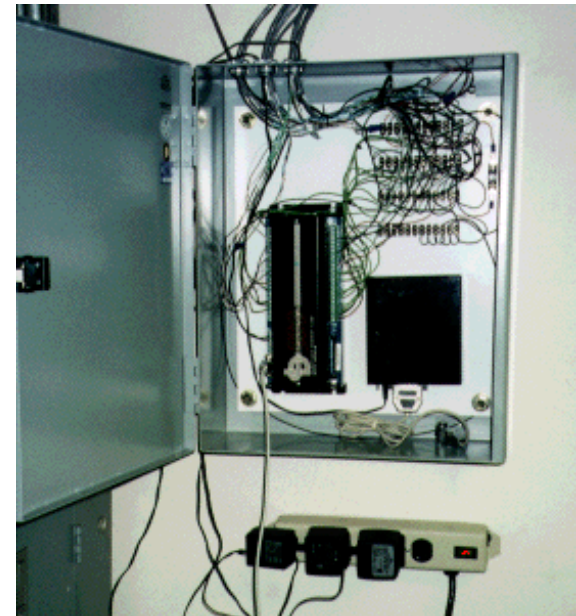
Evaluating the **Direct** and Indirect Benefits of Mitigation Strategies



Evaluating the Direct and Indirect Benefits of Mitigation Strategies



Quantifying the Direct Effects of Urban Heat Island Mitigation



Demonstrated Energy Savings of High-Albedo Roof Systems in Florida

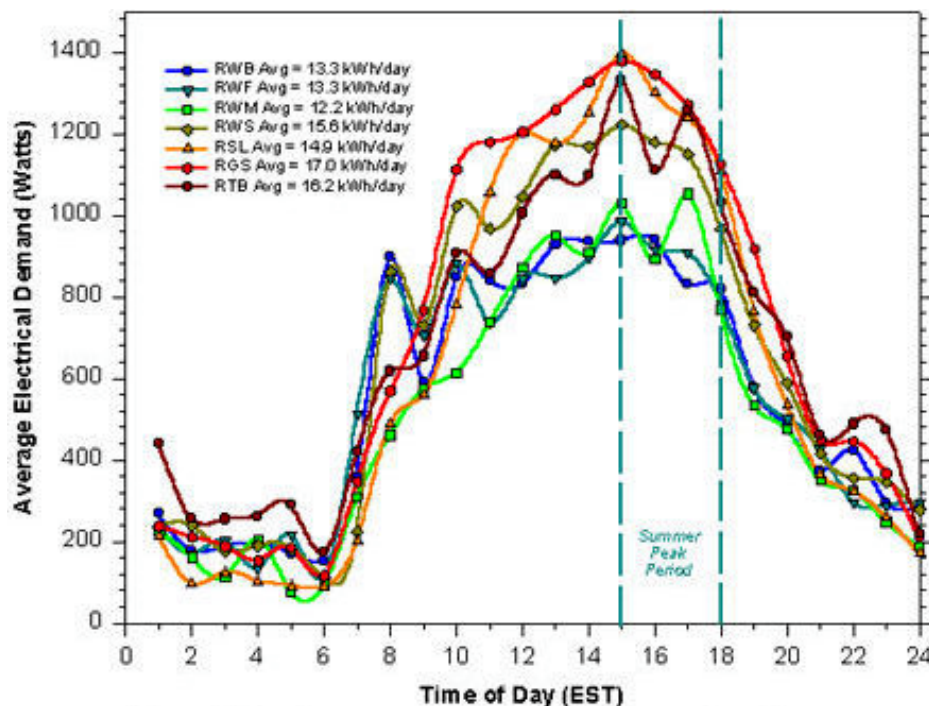
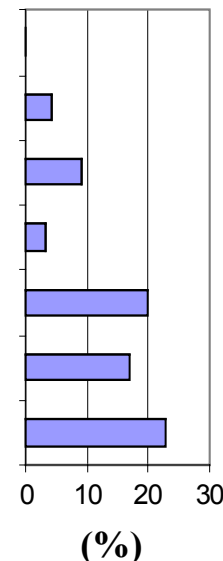


Figure E-4. Average space cooling demand and profiles over the unoccupied period.

- RGS – Control
- RWS – Light shingles
- RSL – Dark shingles*
- RTB – Terra cotta tile
- RWD – White S-tile
- RWF – White flat tile
- RWM – White metal

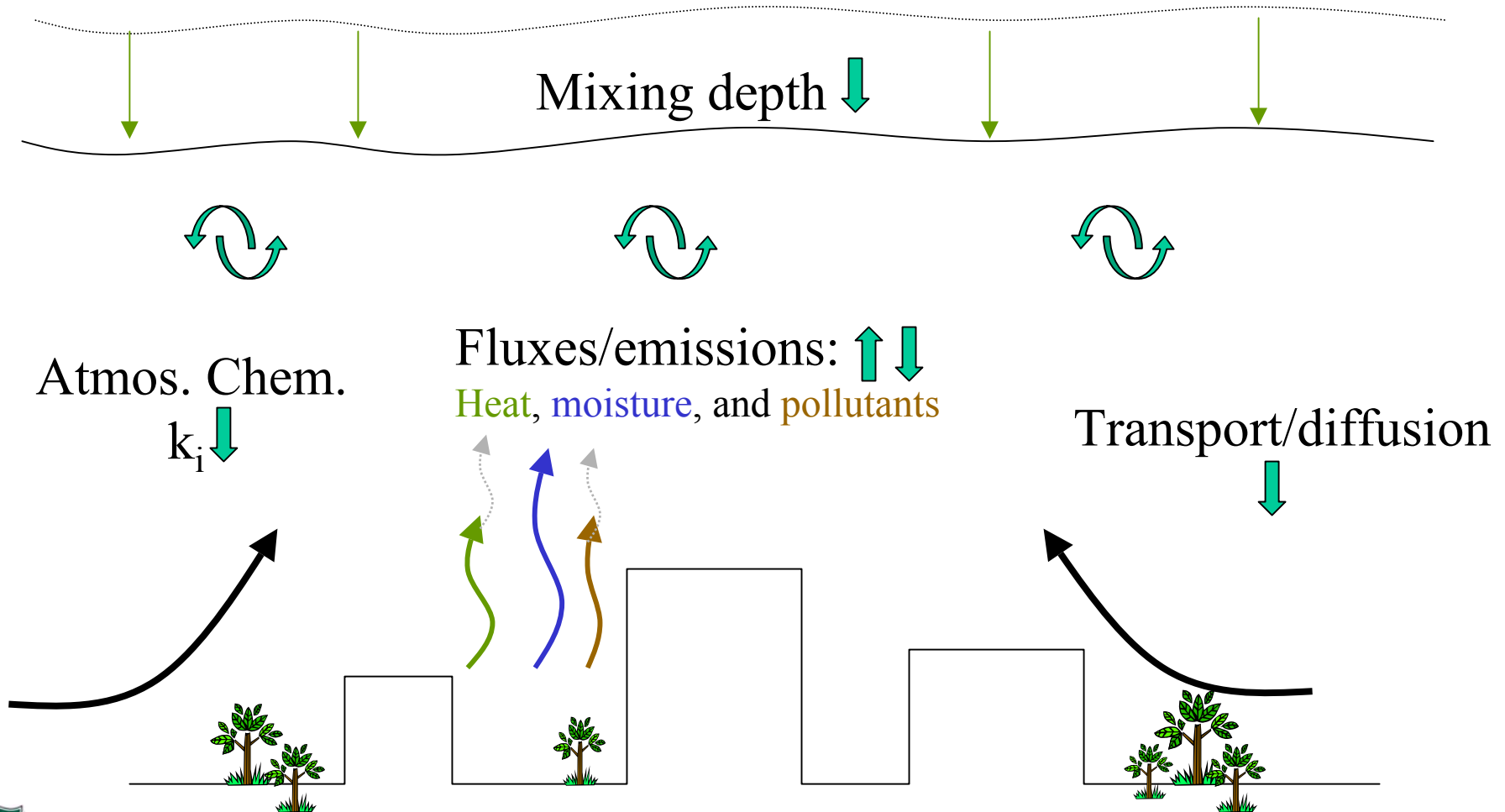
* Sealed, R-19

Cooling Savings

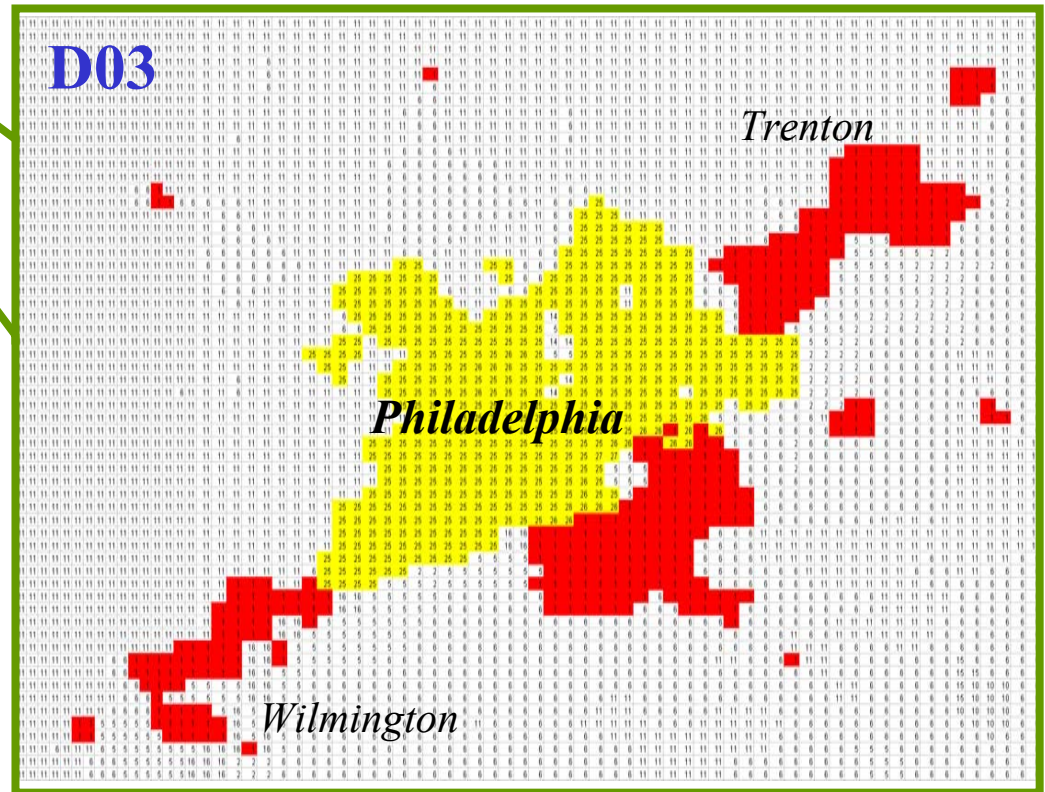
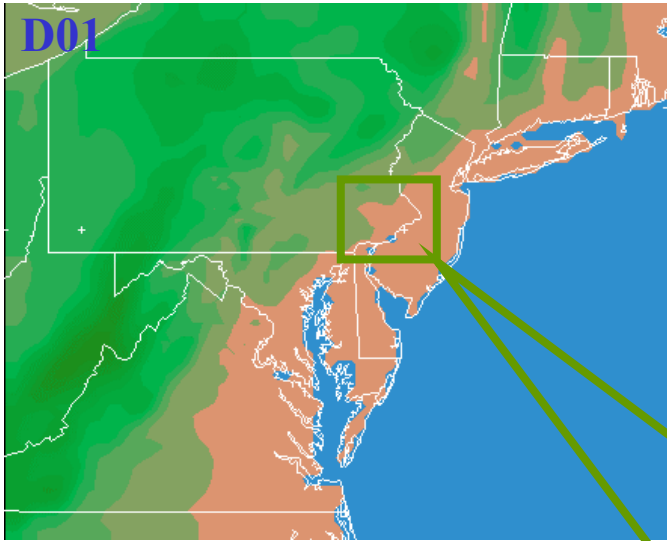


Estimating the Indirect Effects of Urban Heat Island Mitigation

Qualitative Effects of Mitigation



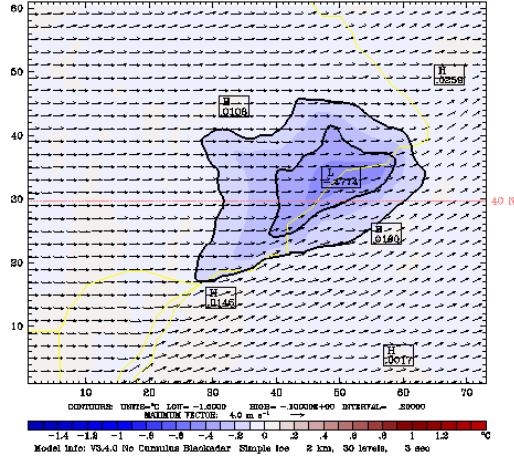
Atmospheric Modeling Domains (18-6-2 km nests)



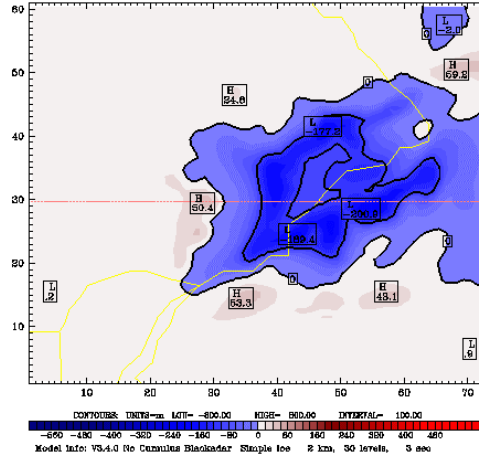
- PSU/NCAR MM5 model
- Control run
- Albedo modification
- Vegetation modification

Alb1 7/29/99:1200LST

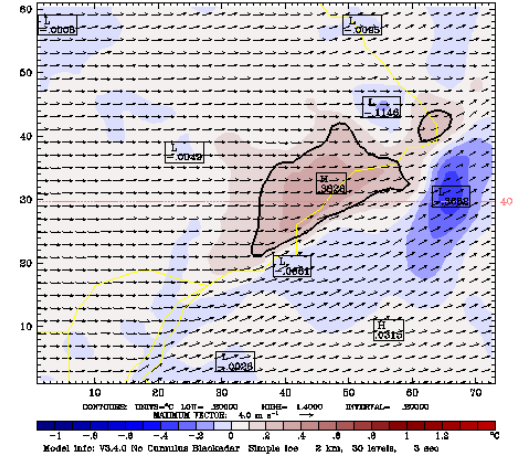
ΔT (C)



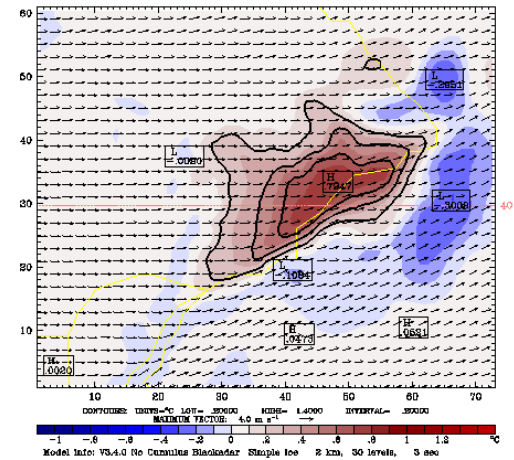
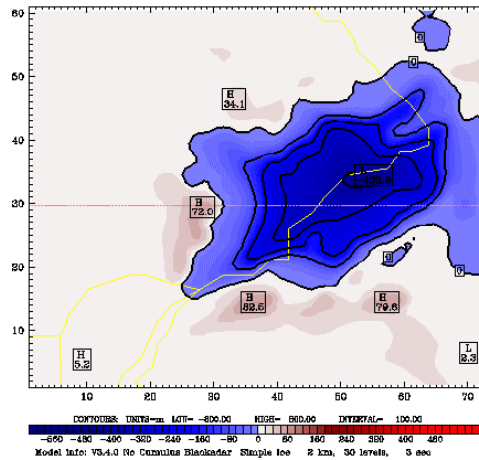
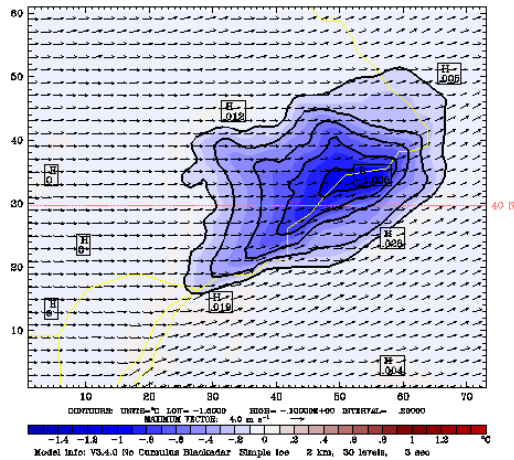
ΔPBL (m)



ΔT_{dp} (C)



Alb2 7/29/99:1200LST



Streamlined Mesoscale Modeling of Heat Island Mitigation Strategies

CITIES

- Atlanta
- Baltimore
- Baton Rouge
- Charlotte
- Detroit
- Grand Rapids
- Houston
- New Orleans
- Philadelphia
- Washington

EPISODES

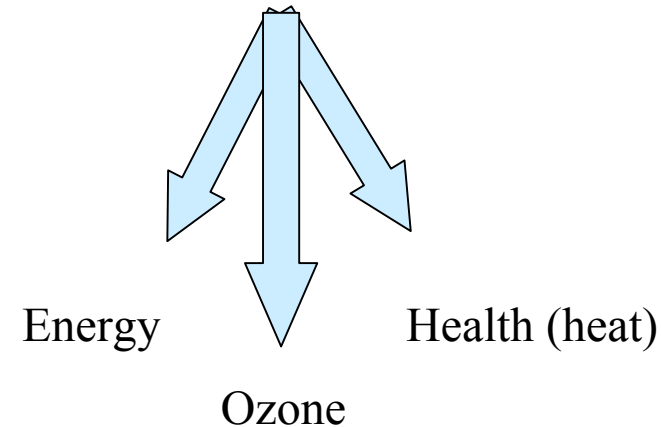
- Ozone
- Heat Waves
- Weather patterns

STRATEGIES

- Albedo
- Vegetation
- Albedo and Vegetation

IMPACTS

- Temperature
- Humidity
- Wind speeds



Conclusions

- Urban areas produce a measurable thermal signature that impacts air quality, energy consumption, and human health
- Causes of the urban heat island include relatively low reflectivity of urban surfaces and generally low vegetative cover
- High albedo surfaces and urban forestry programs can have both direct and indirect impacts on the urban environment
- Complex meteorological response to mitigation strategies requires detailed modeling to investigate the full range of potential implications.

